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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant:	Heywood, *et al.*	Examiner:	Harris, Katrina B.
Serial No.:	10/755,541	Art Unit:	3747
Filed:	January 12, 2004		
Title:	**HIGH COMPRESSION RATIO, HIGH POWER DENSITY HOMOGENEOUS CHARGE COMPRESSION IGNITION ENGINES USING HYDROGEN AND CARBON MONOXIDE TO ENHANCE AUTO-IGNITION RESISTANCE**		

Mail Stop Amendment
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

DECLARATION UNDER 37 C.F.R. § 1.131

I, Daniel R. Cohn, declare as follows:

1. I am a senior research scientist at the Plasma Science and Fusion Center at the Massachusetts Institute of Technology in Cambridge, Massachusetts.

2. I am a co-inventor of the above-identified patent application.

3. I am submitting this declaration to establish completion of the invention disclosed and claimed in the above-identified application prior to the publication date of European Patent Application EP 1378644A2. This European patent application was published on January 7, 2004.

4. All of the events set forth in this declaration took place in the United States of America.

5. On a date prior to January 7, 2004, my co-inventors and I invented a high compression ratio, homogeneous charge compression ignition/spark ignition dual mode engine having a first mode employing homogeneous charge compression ignition at low- and mid-load levels and a second mode employing spark ignition at high-load levels, the second mode including the addition of

hydrogen or a hydrogen/carbon monoxide mixture in the engine. The invention also includes a high compression ratio, homogeneous charge compression ignition engine operating on a high cetane fuel along with the addition of hydrogen or a hydrogen/carbon monoxide mixture at low- to mid-load levels.

6. Exhibit 1 attached hereto is a document having a heading "Disclosure" and entitled "High Compression Ratio, High Power Density Homogeneous Charge Compression Ignition (HCCI) Engines Using Hydrogen and Carbon Monoxide to Enhance Auto-Ignition Resistance."

7. The original of Exhibit 1 bore dates in the upper right hand corner prior to January 7, 2004. These dates have been redacted from Exhibit 1.

8. Exhibit 1 discloses the inventions disclosed and claimed in the above-identified patent application.

9. Prior to January 7, 2004, the disclosure of Exhibit 1 was sent to Sam Pasternack, the attorney engaged by the Massachusetts Institute of Technology to prepare and file a patent application.

10. On a date prior to January 7, 2004, Mr. Pasternack sent me a first draft of a patent application based on the disclosure of Exhibit 1.

11. My co-inventors and I reviewed the draft and provided comments to Mr. Pasternack.

12. On January 13, 2004, Mr. Pasternack informed me that the patent application had been filed in the United States Patent and Trademark Office on January 12, 2004.

13. I further declare that all statements made of my own knowledge are true and that all statements made on information and belief are believed to be true. I have also been warned that

willful false statements and the like are punishable by fine or imprisonment, or both, under 18 U.S.C. 1001 and may jeopardize the validity of the application or any patent issuing thereon.

Daniel R. Cohn

Daniel R. Cohn

August 2, 2006

Date

EXHIBIT 1

DISCLOSURE

HIGH COMPRESSION RATIO, HIGH POWER DENSITY HOMOGENEOUS CHARGE COMPRESSION IGNITION (HCCI) ENGINES USING HYDROGEN AND CARBON MONOXIDE TO ENHANCE AUTO-IGNITION RESISTANCE

Continuation-in-part to MIT Case 10,020 (J.B. Heywood et. al.)

MIT Case 10,020 previously disclosed the use of hydrogen, and hydrogen and carbon monoxide mixtures, to enhance knock resistance to improve the performance of spark ignition gasoline engines. The enhanced knock resistance is a manifestation of the increased resistance to autoignition, the self ignition of a fuel-air mixture under sufficient temperature and pressure. As described in MIT case 10,020, the addition of hydrogen and carbon monoxide was observed to have a substantial effect on knock resistance. This new disclosure discusses its use to improve the performance of a gasoline engine that uses homogeneous charge compression ignition (HCCI) in combination with spark ignition (SI) operation. It also discusses the use of hydrogen and carbon monoxide enhanced auto-ignition

resistance to improve the operation of HCCI engines in combination with diesel engine operation..

HCCI is a new engine combustion concept which offers a means to increase the efficiency of gasoline fueled engines. Use of HCCI combustion rather than spark ignition combustion enables well-mixed very lean fuel-air mixtures to be burned rapidly inside the engine cylinder at high engine compression ratio. These conditions give high engine efficiency and exceptionally low NO_x, CO, and particulate emissions. However, it is extremely difficult in a practical engine concept to make gasoline HCCI combustion work satisfactorily at all loads, and in particular at high engine loads. HCCI also does not work well near idle because at very light loads it is difficult to achieve complete enough combustion of the fuel. . Practical gasoline engine concepts which use the HCCI combustion mode utilize it between low- and mid-load levels, and return to the normal spark-ignition combustion mode at high loads. Such combined engine concepts thus have a severe knock problem to overcome in this high-load spark-ignition engine operating mode if the high compression ratio (up to about 15:1) desirable for the HCCI mode is used. If the compression ratio is reduced to normal values (~ 10:1) to avoid this knock problem, much of the part-load HCCI efficiency benefit is lost. In addition, the onset of knock at high loads also limits the use of turbocharging to increase engine power density and decrease engine size.

This problem can be avoided by using hydrogen, or a hydrogen plus carbon monoxide mixture that might be produced by a gasoline fuel reformer, to enhance the octane rating and hence knock resistance of the gasoline under these high-load, high-compression-ratio and possible highly boosted operating conditions. As discussed in MIT case 10,020, we have shown recently that modest amounts of hydrogen addition to the gasoline vapor/air mixture within the engine

cylinder can raise the gasoline fuel's octane number by 10 or more numbers. When CO is mixed with the H_2, with roughly equal energy content in each of these added gases, the impact can be approximately doubled (for the same H_2 energy content). This dual mode engine could also use other low octane hydrocarbon fuels as well as gasoline: the same beneficial effects of hydrogen, or hydrogen and carbon monoxide mixtures addition at high loads would also be obtained.

HCCI using hydrogen enhanced knock resistance would use this feature of H_2 and (H_2 + CO) mixtures as follows. Under HCCI combustion operation, a low octane rating gasoline or other hydrocarbon fuel is attractive since, with HCCI, easier autoignition at lower after compression fuel –air mixture temperatures within the cylinder is desirable. Such autoignition characteristics go with lower octane rating fuels. Then, outside the HCCI combustion regime, where normal spark-ignition combustion is used, the knock problem resulting from the engine's high compression ratio is avoided by adding sufficient H_2 (or H_2 plus CO) to just suppress the knock. The amount of H_2 (or H_2 plus CO) added would have to be increased as engine load was increased above the HCCI/normal spark-ignition combustion boundary. This type of HCCI engine operation is shown in fig 1.

In light-duty vehicle operation, most of the driving is done with the engine lightly loaded, so the amount of H_2 required over a driving cycle to avoid knock at high load conditions is not excessive. The hydrogen could be stored in a small high pressure tank which is refueled when the gasoline tank is refueled. Alternatively, the hydrogen, with accompanying CO, could be produced in a reformer from gasoline or some other hydrocarbon fuel. A variety of reformers might be used including plasmatron reformers. In certain situations, some amount of hydrogen

and/or carbon monoxide may also be used on the engine at low to mid-loads. For example, it may be desirable to operate an onboard reformer at some level throughout the drive cycle in order to improve rapid response capability by improving transition between the two combustion modes, which for instance could occur during transition from low torque to high torque during strong acceleration. It may also be useful to vary the combustion rate by stratifying the hydrogen, or the hydrogen and carbon monoxide mixtures, to extend the HCCI operating range, or to reduce noise by slowing down the fastest part of the combustion process. Stratification is the use of inhomogeneous air/fuel mixtures. The stratification can be achieved by having non-uniform distribution of the hydrogen or hydrogen and carbon monoxide mixtures in the cylinder. This can be achieved through non-uniform port fueling, or more likely by in-cylinder injection of the hydrogen rich gas.

The HCCI/spark ignition engine disclosed here is thus attractive in that it uses HCCI where this is feasible and advantageous, uses spark-ignition engine combustion at higher loads where HCCI is not feasible, uses a high compression ratio in all operating modes, permits pressure boosting by turbocharging or other means to increase the engine's output and only requires a modest fraction of its energy to be in the form of hydrogen over normal vehicle driving cycle. The engine can be optimized to take advantage of the benefits of HCCI operation at low and mid loads without being constrained by previous limits on high load performance.

In another embodiment hydrogen or hydrogen and carbon monoxide mixtures, can be used to improve the operation of HCCI engines operating on diesel fuel by making it more difficult for compression ignition to take place at low to mid loads. This gives more time for fuel-air mixing

following injection during the compression stroke thereby producing a more homogeneous charge. At high loads the hydrogen and carbon monoxide addition would be reduced or would cease, thereby allowing the required fast compression ignition with fuels like diesel which have fast autoignition characteristics. This type of HCCI engine is shown in fig. 2.

Benefits of the use at low and mid-load levels of a low cetane diesel fuel with HCCI-like combustion, which makes compression ignition more difficult, has recently been discussed in SAE paper 2003-01-0742. However, the low cetane fuel will not provide the desired diesel-like performance at high loads. The use of hydrogen and/or carbon monoxide enhanced auto-ignition resistance at low to mid load levels allows high cetane fuel to be used at high loads while providing low cetane like characteristics and good mixing at low mid-load levels.

The addition of hydrogen or hydrogen and carbon monoxide from a fuel reformer would be terminated or reduced to a sufficiently low level after the diesel engine load had increased to a sufficiently high level. It may be useful to always keep the fuel reformer operating at some level rather that to turn it off completely.

The ratio of hydrogen, carbon monoxide or hydrogen and carbon monoxide to diesel or another hydrocarbon fuel can be varied so as to obtain the desired ignition delay and to minimize the amount of hydrogen, or hydrogen and carbon monoxide mixtures, that is used.

This type of engine could use other hydrocarbon fuels including bio-diesel fuel.

Possible Claims

1. An engine that uses homogeneous charge compression ignition combustion operating at low and mid-loads and operating with spark ignition combustion mode at higher loads where hydrogen, or hydrogen and carbon monoxide mixtures, is added during spark-ignition operation in such quantity so as to avoid knock by increasing the octane rating of the fuel mixture.
2. The engine of claim 1 where the engine is optimized for operation in HCCI mode in those loads where the engine operates with HCCI combustion .
3. The engine of claim 1 where gasoline is used as a fuel.
4. The engine of claim 1 where a hydrocarbon fuel other than gasoline is used. as a fuel.
5. 5..The engine of claim 1 where the hydrogen is provided by an onboard hydrogen storage tank.
6. The engine system of claim 1 where hydrogen and carbon monoxide is produced by an onboard reformer.
7. The engine system of claim 1 where hydrogen or hydrogen and carbon monoxide mixtures is also present in the engine at low and mid-loads.
8. The engine system of claim 1 where hydrogen or hydrogen and carbon monoxide mixtures is used to operate the engine as a spark ignition engine during transition between modes, with the hydrogen or hydrogen and carbon monoxide mixtures stratified.
9. A homogeneous charge compression ignition engine where hydrogen, carbon monoxide, or hydrogen and carbon monoxide is added at low and mid-loads to delay ignition
10. The engine of claim 9 where the engine is optimized for operation in HCCI mode in those loads where the engine operates with HCCI combustion .

11. The engine of claim 9 where diesel fuel is used

12. The engine of claim 9 where a hydrocarbon fuel other than diesel fuel is used

13. The engine system of claim 9 where bio-diesel fuel is used

14. The engine system of claim 9 where hydrogen, carbon monoxide, or hydrogen and carbon monoxide is not used above a certain load

15. The engine system of claim 9 where hydrogen, carbon monoxide or hydrogen and carbon monoxide to the diesel or other hydrocarbon fuel is reduced above a certain load

16. The engine system of claim 9 where the ratio of hydrogen, carbon monoxide or hydrogen and carbon monoxide to diesel or another hydrocarbon fuel is determined by the amount needed to obtain the desired ignition delay

17. The engine system of claim 9 where the ratio of hydrogen, carbon monoxide or hydrogen and carbon monoxide to diesel or some other hydrocarbon fuel is varied so as to minimize the amount required to obtain the desired ignition delay.

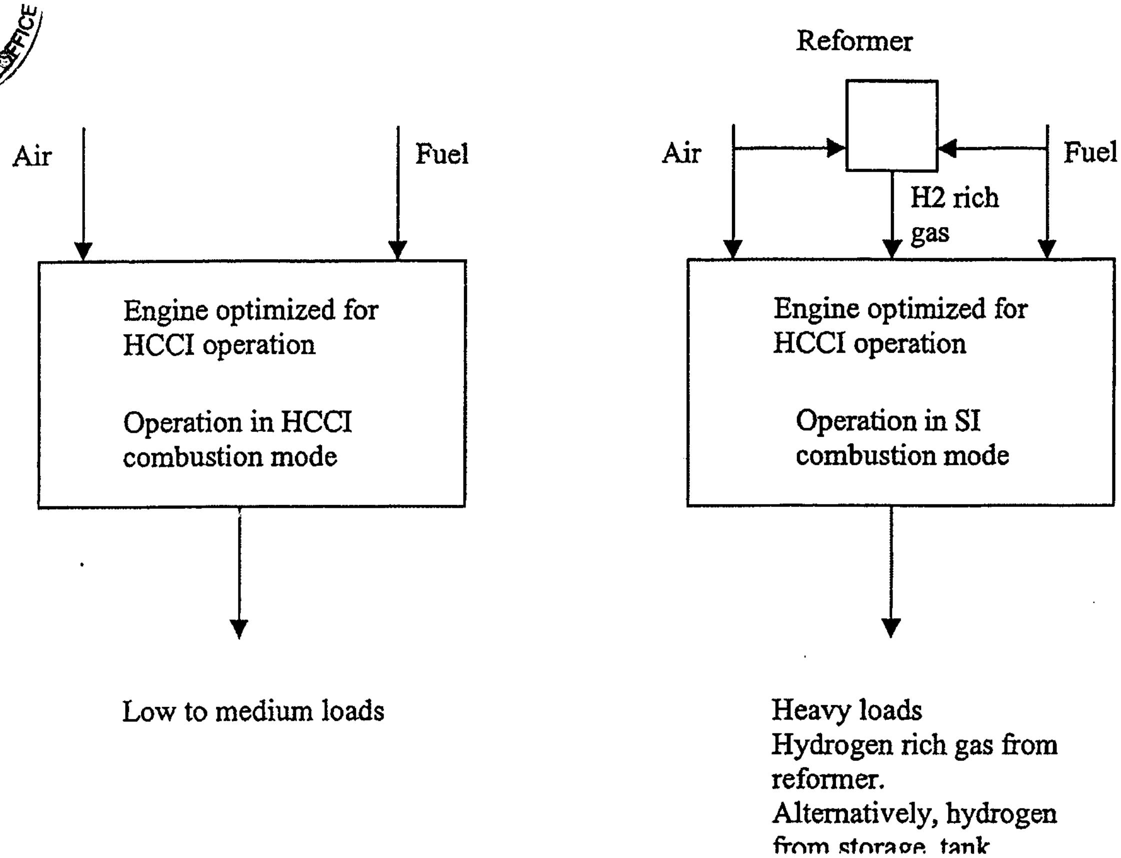

Figure 1. Operation of optimized HCCI engine as a spark engine at high loads..Engine uses Lower octane gasoline or other hydrocarbon fuel.

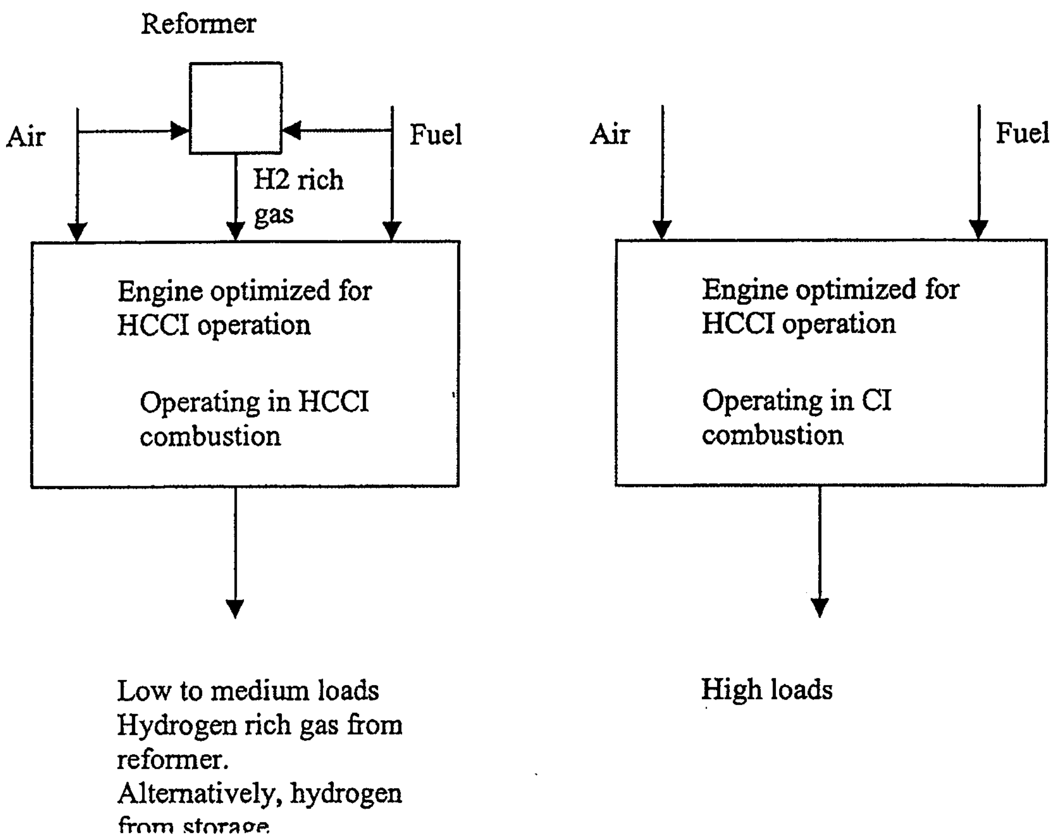

Figure 2. Operation of optimized HCCI engine as a CI engine at high loads . Engine uses or other high cetane fuel.